

Comets, Origin of Life, and the Rosetta Mission

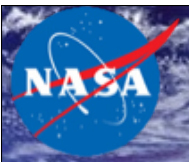
Murthy S. Gudipati

*Jet Propulsion Laboratory, California Institute of Technology,
Pasadena, CA 91109*



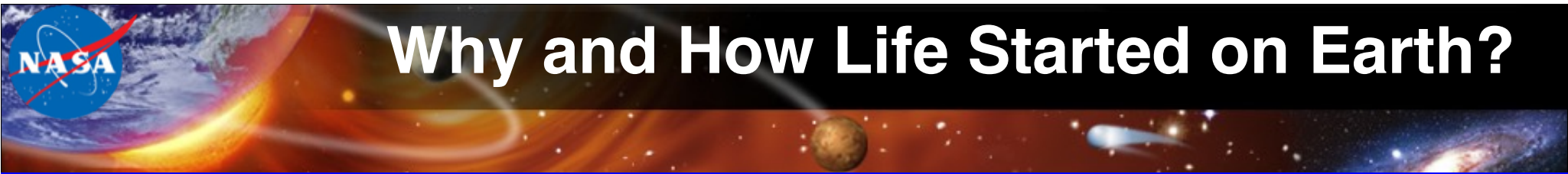
Is There Life On Earth?

Yes, Of Course
Bacteria, Plants, Ocean
Life, Birds, Bees, Animals
(including Humans!)
and so on...



There is Life on Earth!





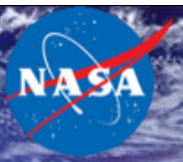
Why and How Life Started on Earth?

Why is Life on Earth?

How Life Originated on Earth?

Is There Life Elsewhere in the Universe?

NASA and other Space Agencies Worldwide are working
Together to Answer the Second TWO Questions!



Hello: Life Out There - Can You Hear Us?

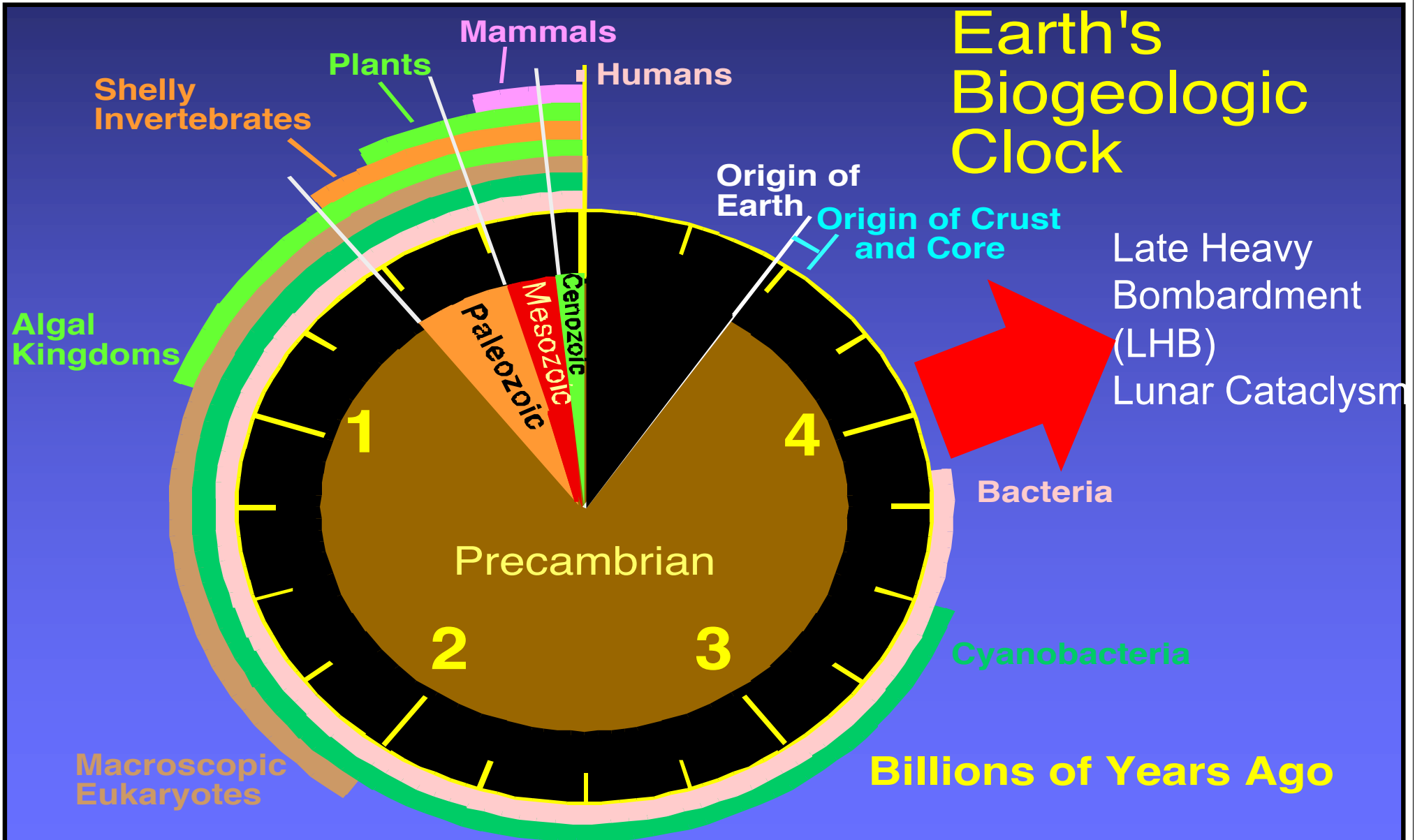
Silence

so far



Life on Earth and Comets – The Link

Water & Organic Matter delivered to Earth by Comets/Asteroids ~4 Billion Years Ago





The Origin of Life on Earth – The Role of Comets

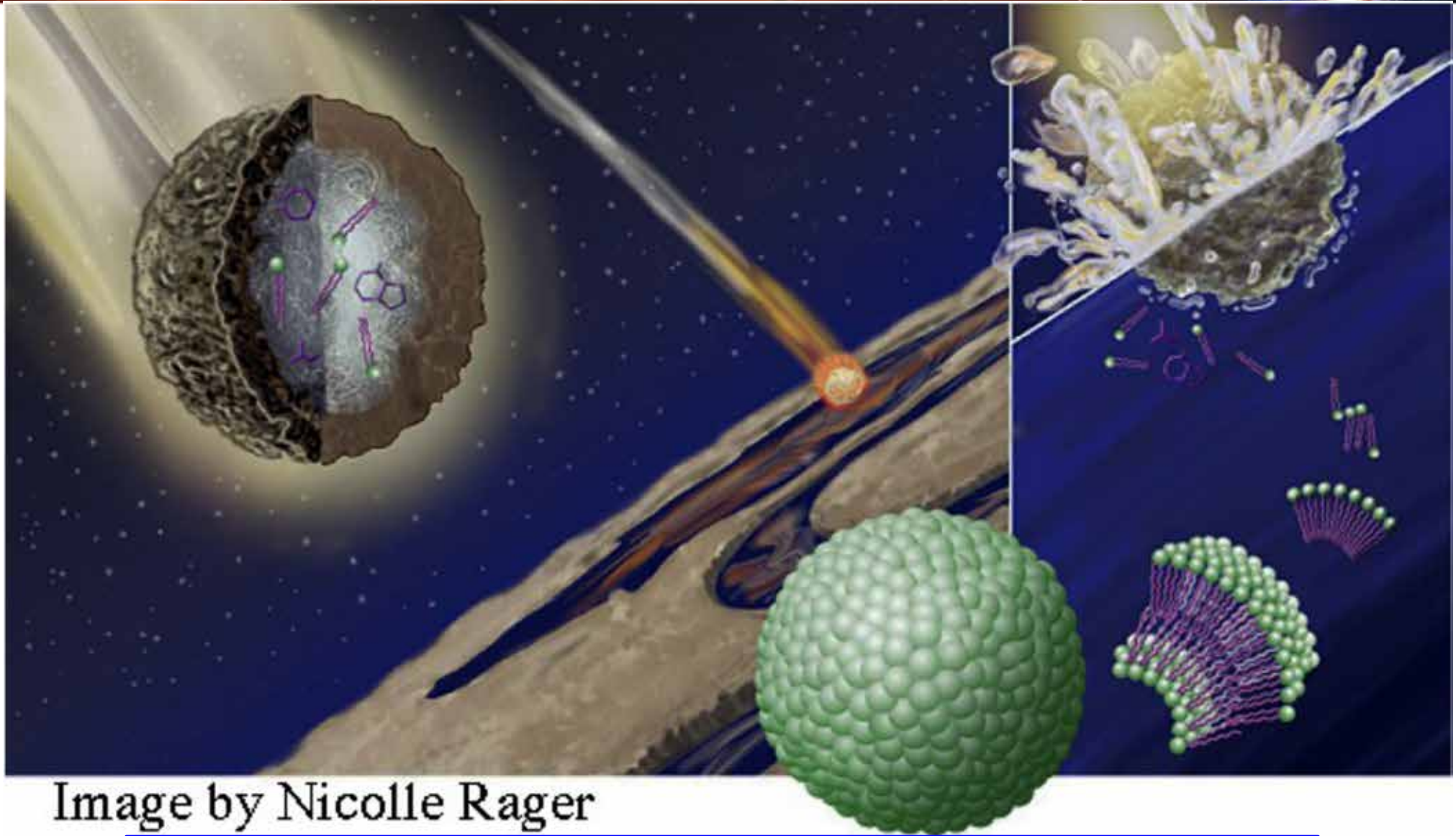


Image by Nicolle Rager

Did Organics Survive Comet Entry and Impacts on Earth?
Do we fully understand Comets? (Deep Impact, Epoxi, Rosetta)

What are comet? The most spectacular objects!

Hale-Bopp



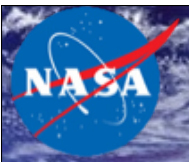
million kilometers of gas/dust tail



Hale-Bopp
Taken 2/20/97 with Red Back Sanyo Park
Celestron Epoch 8" f/5 Schmidt camera
© 1997 Luke Kim Tan



McNaught

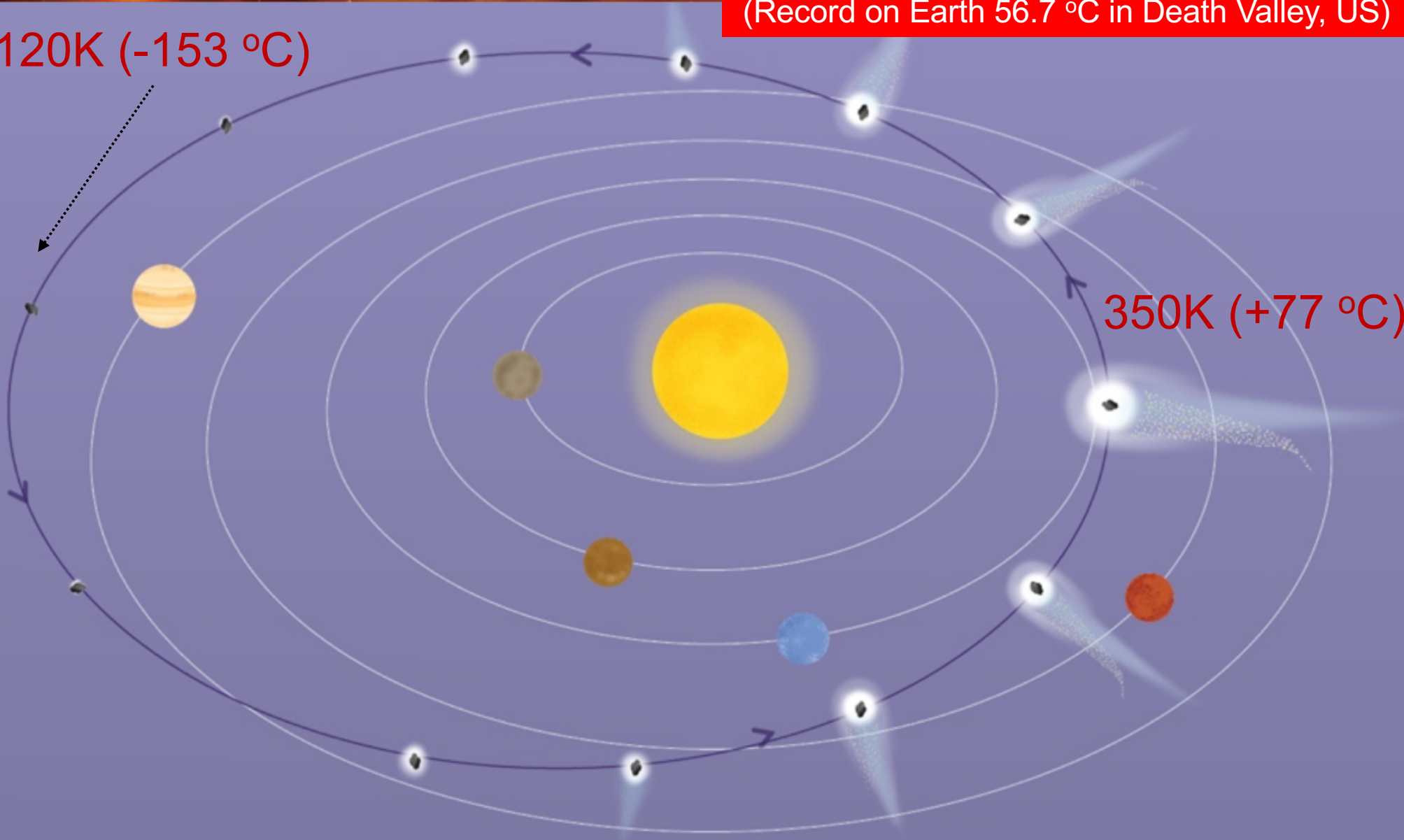


Comets Light Up When Closer to the Sun

The max. Temp. on 67P is around 80 °C
(Record on Earth 56.7 °C in Death Valley, US)

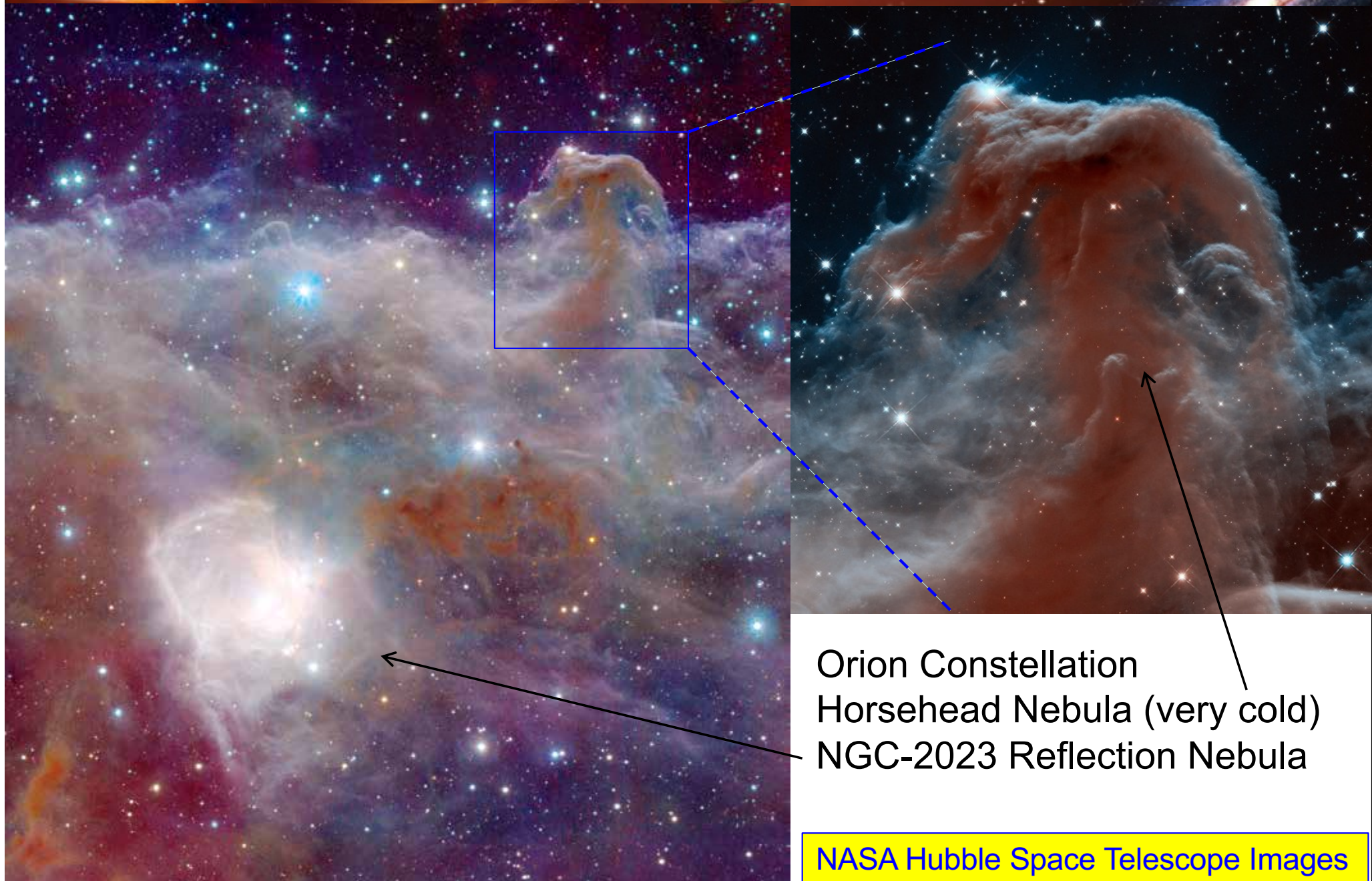
120K (-153 °C)

350K (+77 °C)





Interstellar Molecular Clouds: Birthplaces for New Stars



Orion Constellation
Horsehead Nebula (very cold)
NGC-2023 Reflection Nebula

Formation of our Solar System from Dust, Ice, and Gas in the Molecular Clouds

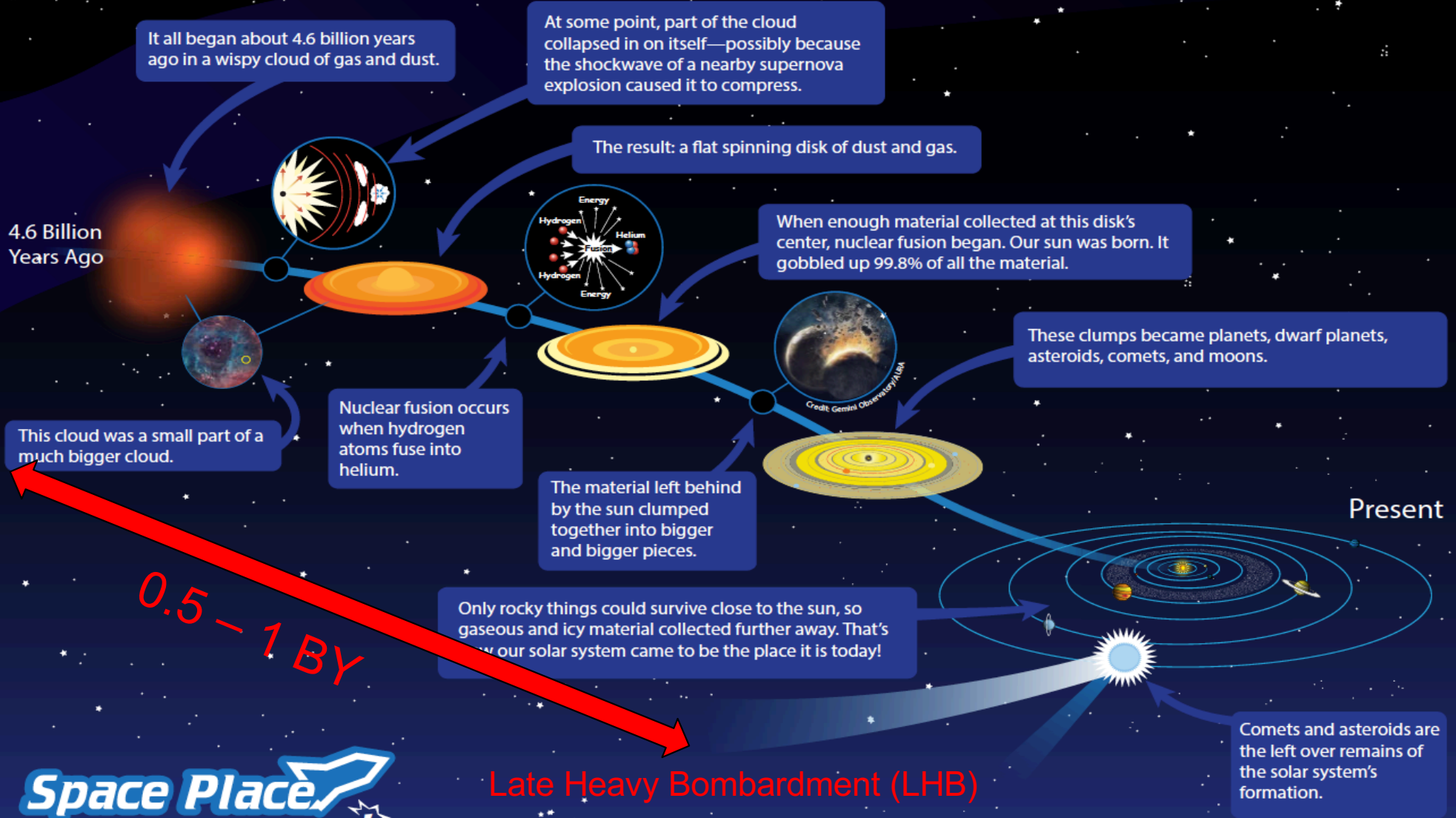


NASA Comet's Journey Started 4.6 Billion Years Ago

National Aeronautics and
Space Administration



How did our solar system come to be?



Space Place
in a Snap!

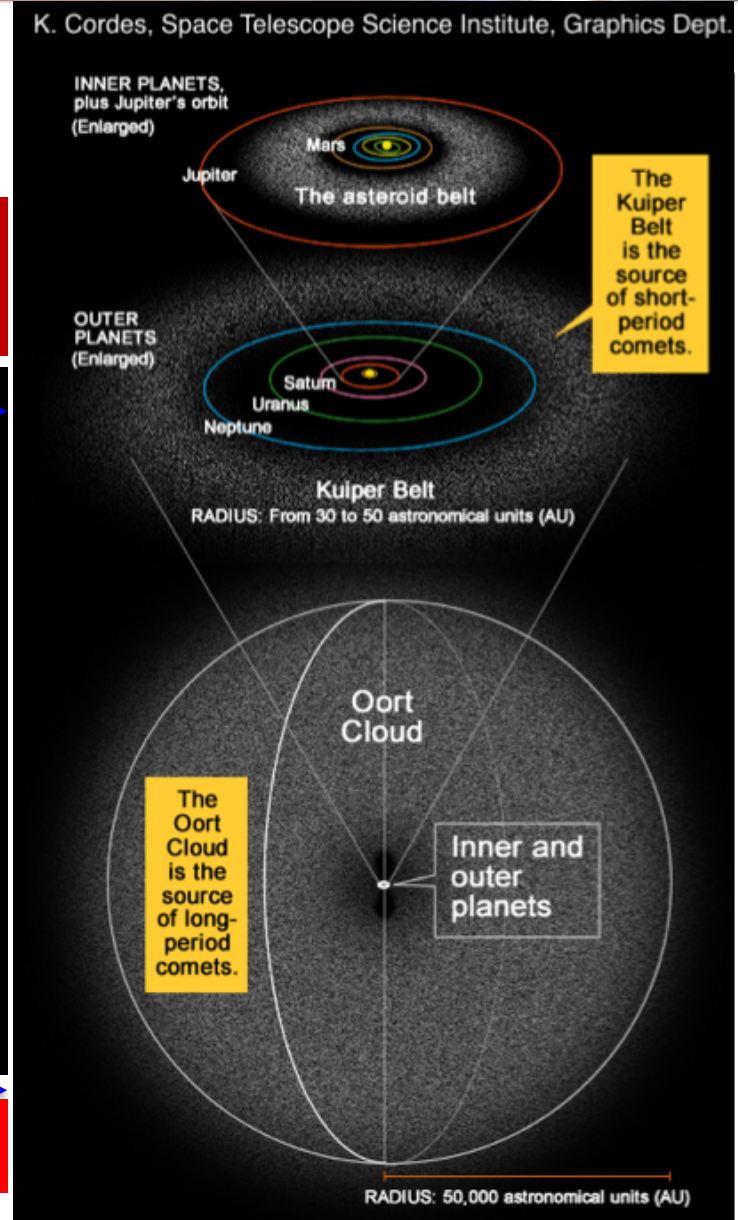
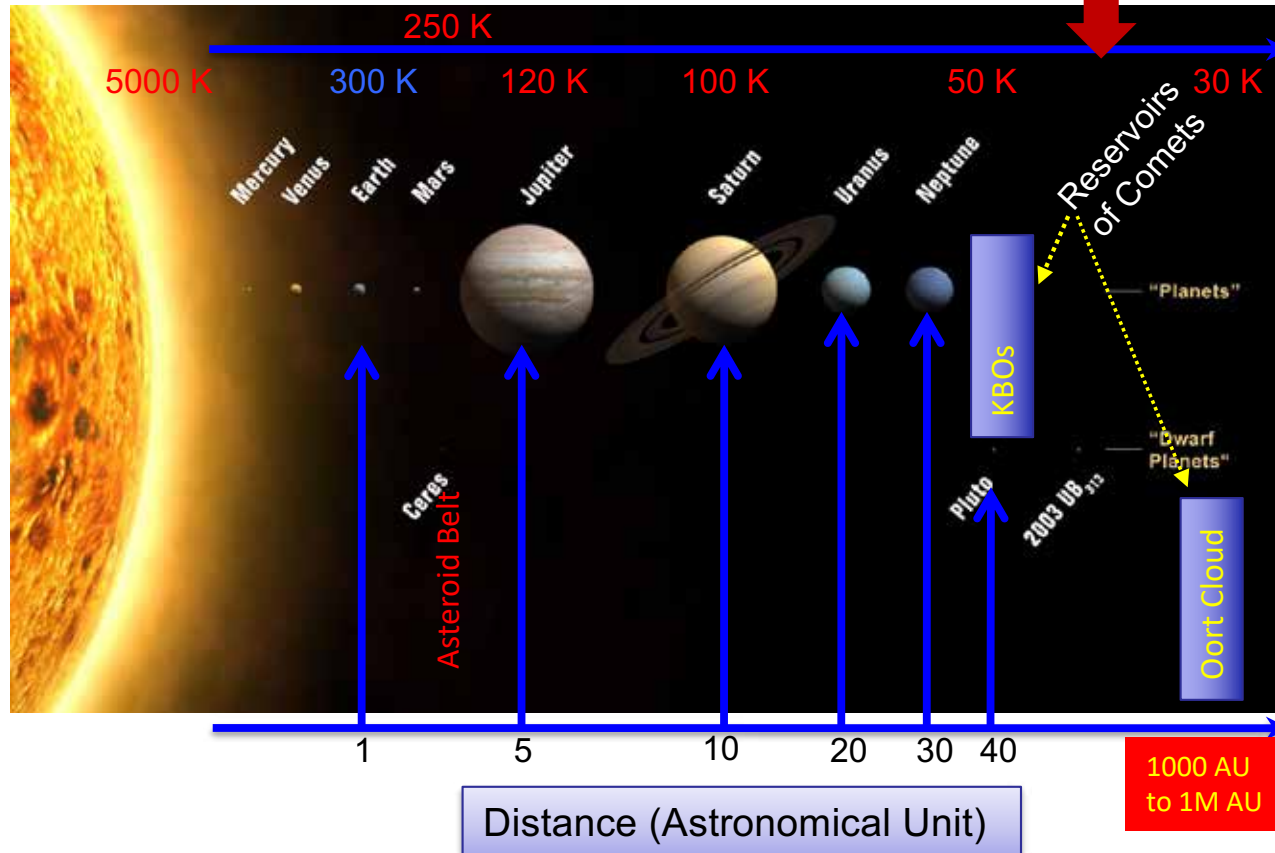


Reservoirs of Comets in Our Solar System

Unaltered, Unfractionated, Km-Size
Icy Bodies Enriched with Organics

Kuiper Belt
Oort Cloud

100 AU
(Voyagers)

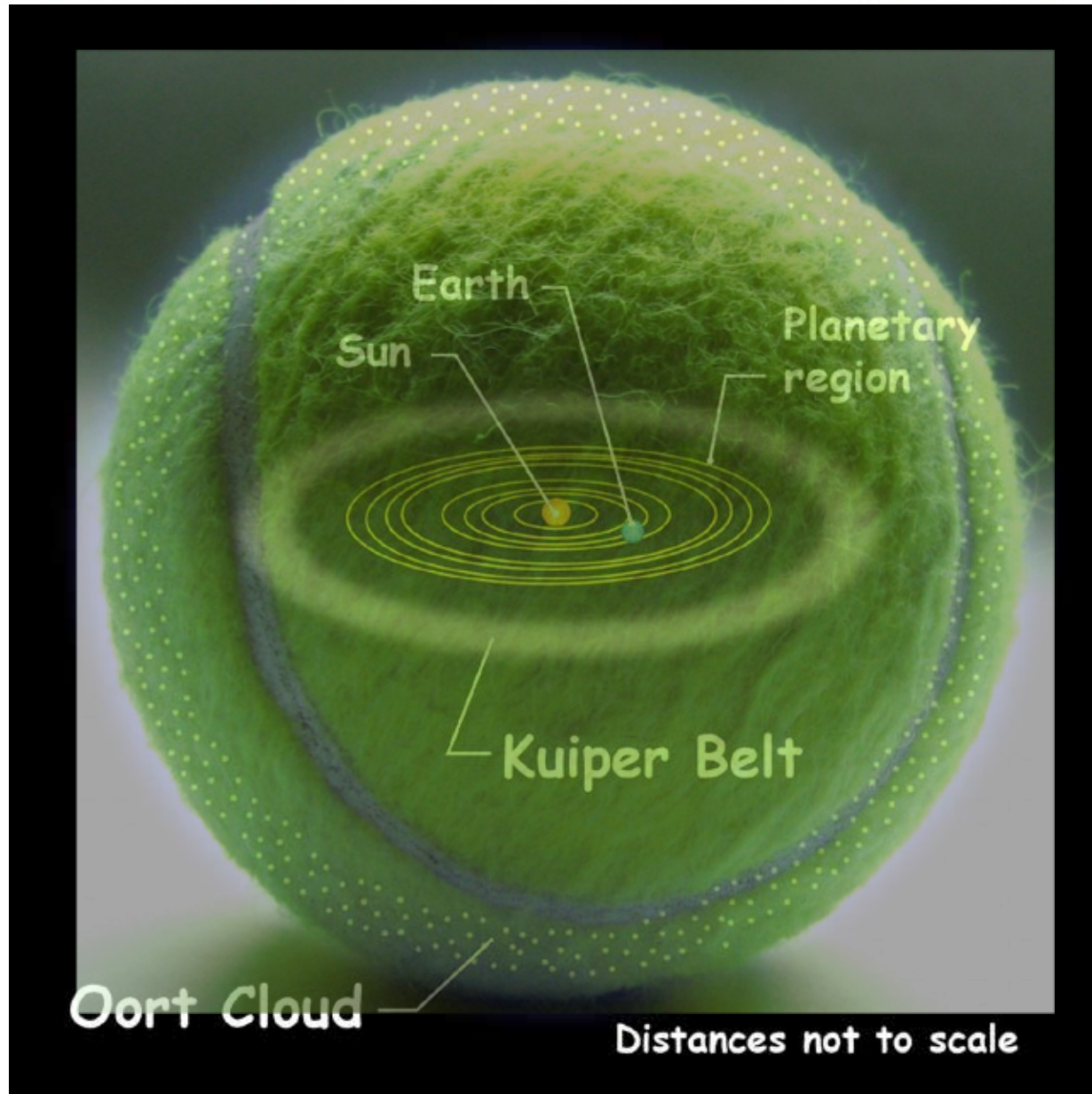


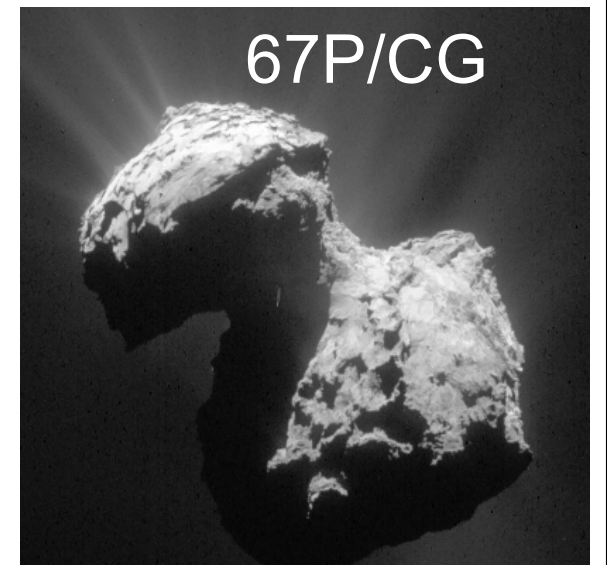
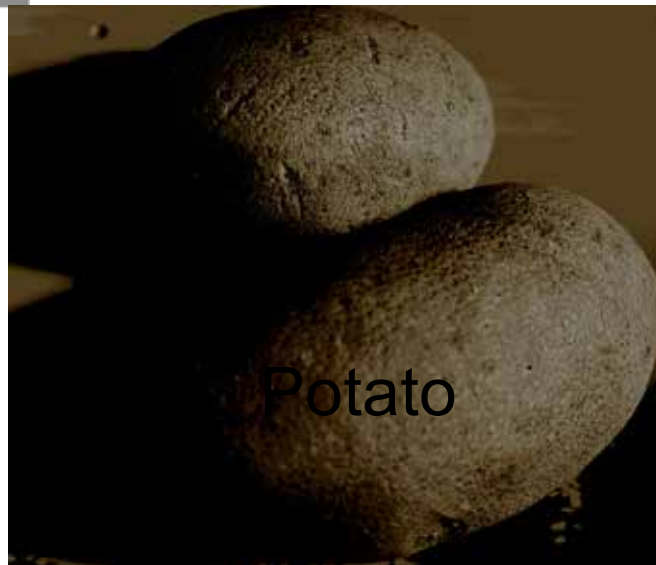
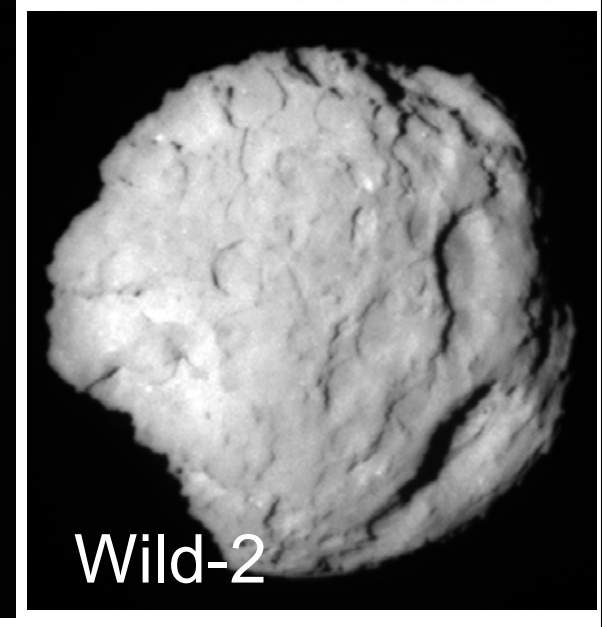
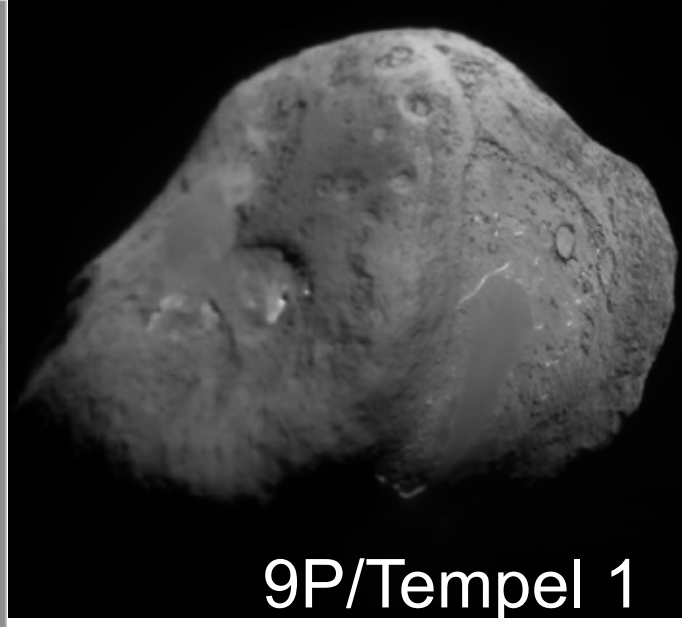
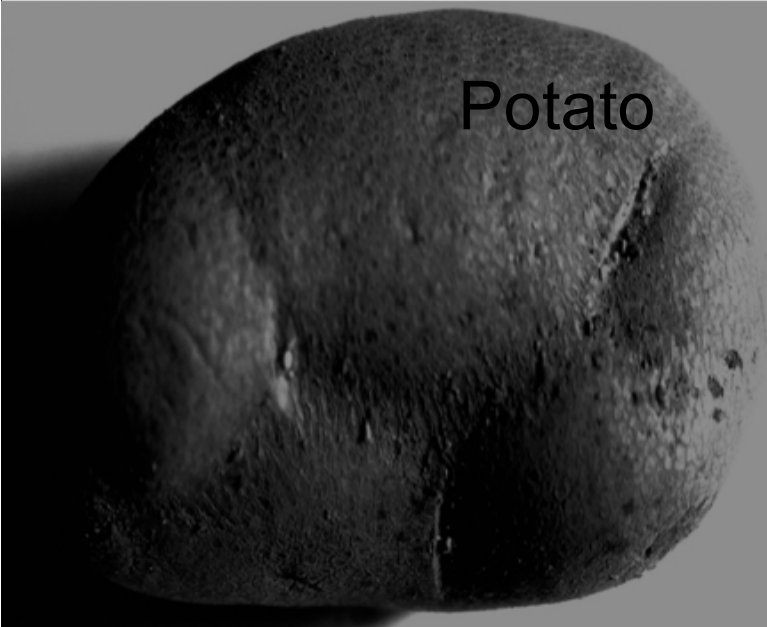


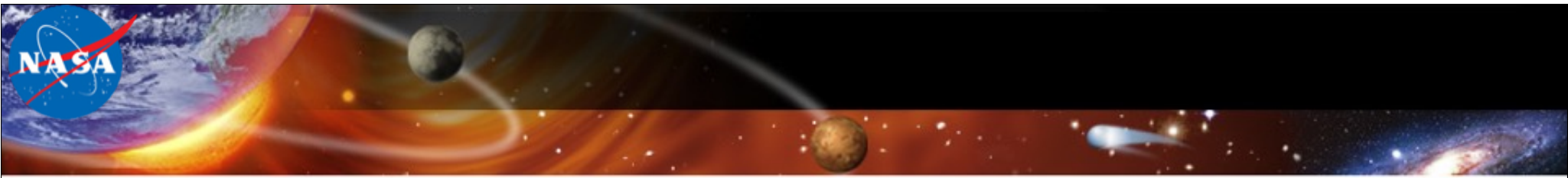
While Earth
Is NOT Flat

Our Solar System
Is mostly a Disk

A Tennis Ball with
a Disk inside!



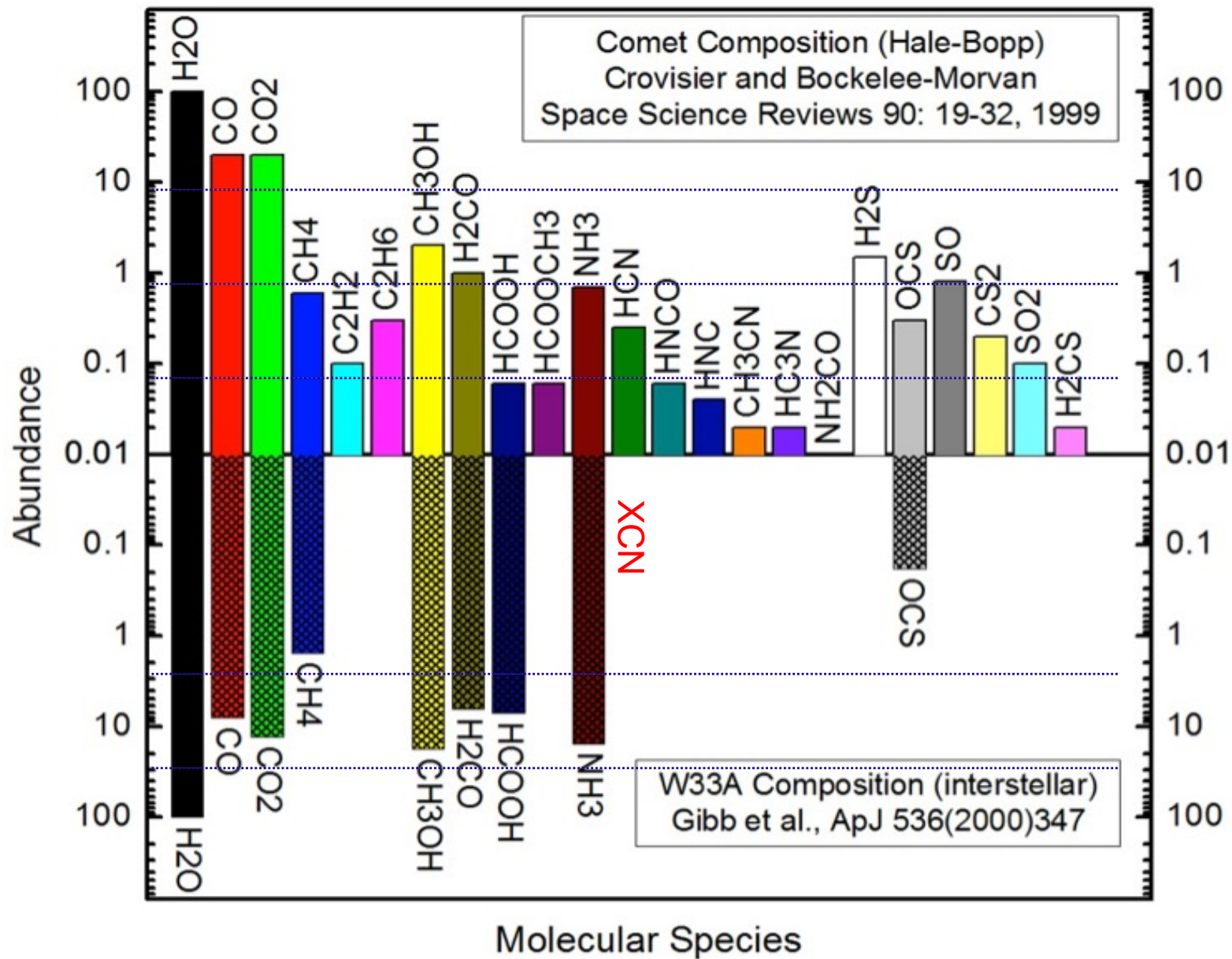




Primordial Matter in Comets



Similar Composition: Comets and Pre-Solar Ice

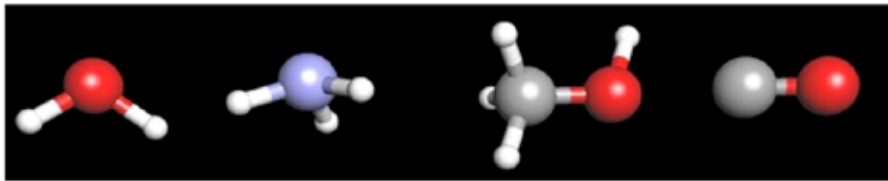




Prebiotic Evolution

Biodegradation

Cryogenic
Solar
System Ices

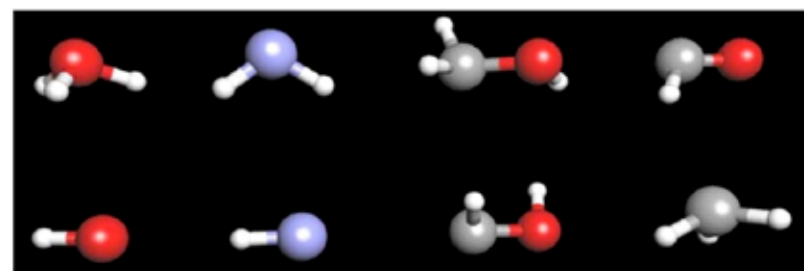


Raw Material
 H_2O , NH_3 , CH_3OH ,
 CO , PO_4 , SO_4 , etc

Photons/Electrons
Cosmic Rays
Debris/Collisions

*Radiation
Processing*

Fundamental
Building Blocks
of Life



Radicals,
Ions,
Electrons, &
Molecules

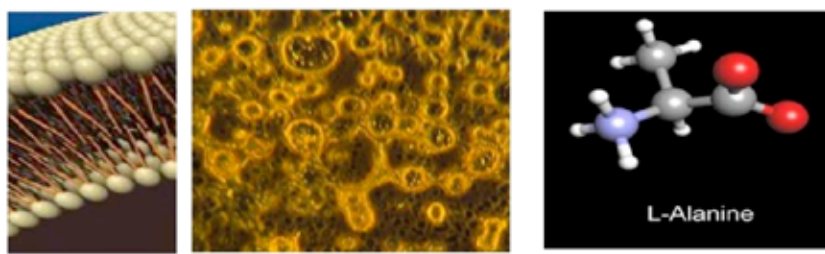
Temperature

Chemistry

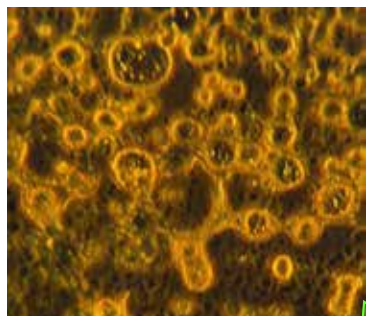
Biomolecules

Amino Acids,
Nucleotides,
Micelles, etc.

Prebiotic
Synthesis

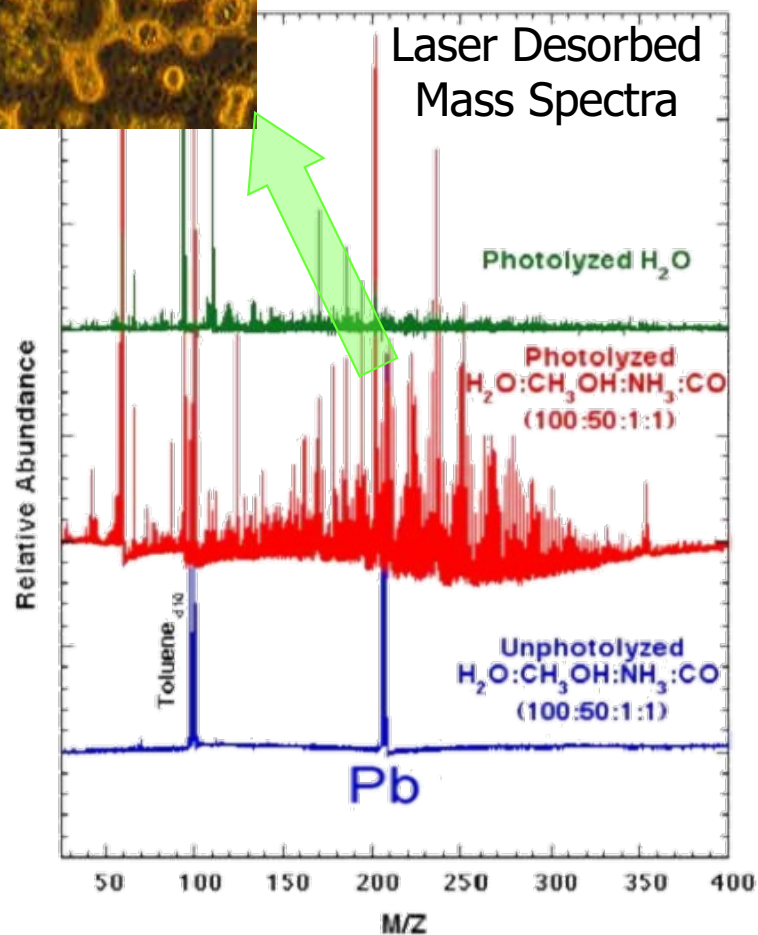


NASA Prebiotic Chemistry in Interstellar Ice Analogs

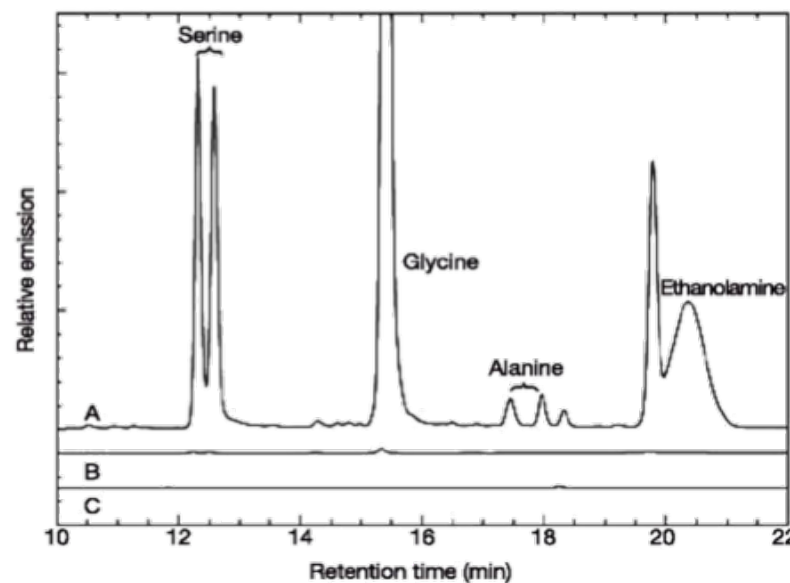
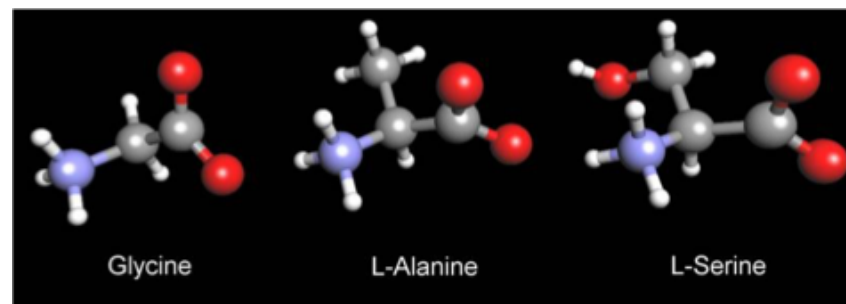


Micelles from VUV-Irradiated
 $\text{H}_2\text{O}:\text{CH}_3\text{OH}:\text{CO}:\text{NH}_3$ Ice Residue
 (100:50:1:1) [NASA Ames Group]

Laser Desorbed
 Mass Spectra



Amino Acids from VUV-Irradiated
 NASA Ames Group ($\text{H}_2\text{O}:\text{CH}_3\text{OH}:\text{NH}_3:\text{HCN} = 20:2:1:1$)
 Leiden Group ($\text{H}_2\text{O}:\text{CH}_3\text{OH}:\text{NH}_3:\text{CO}:\text{CO}_2 = 2:1:1:1:1$)

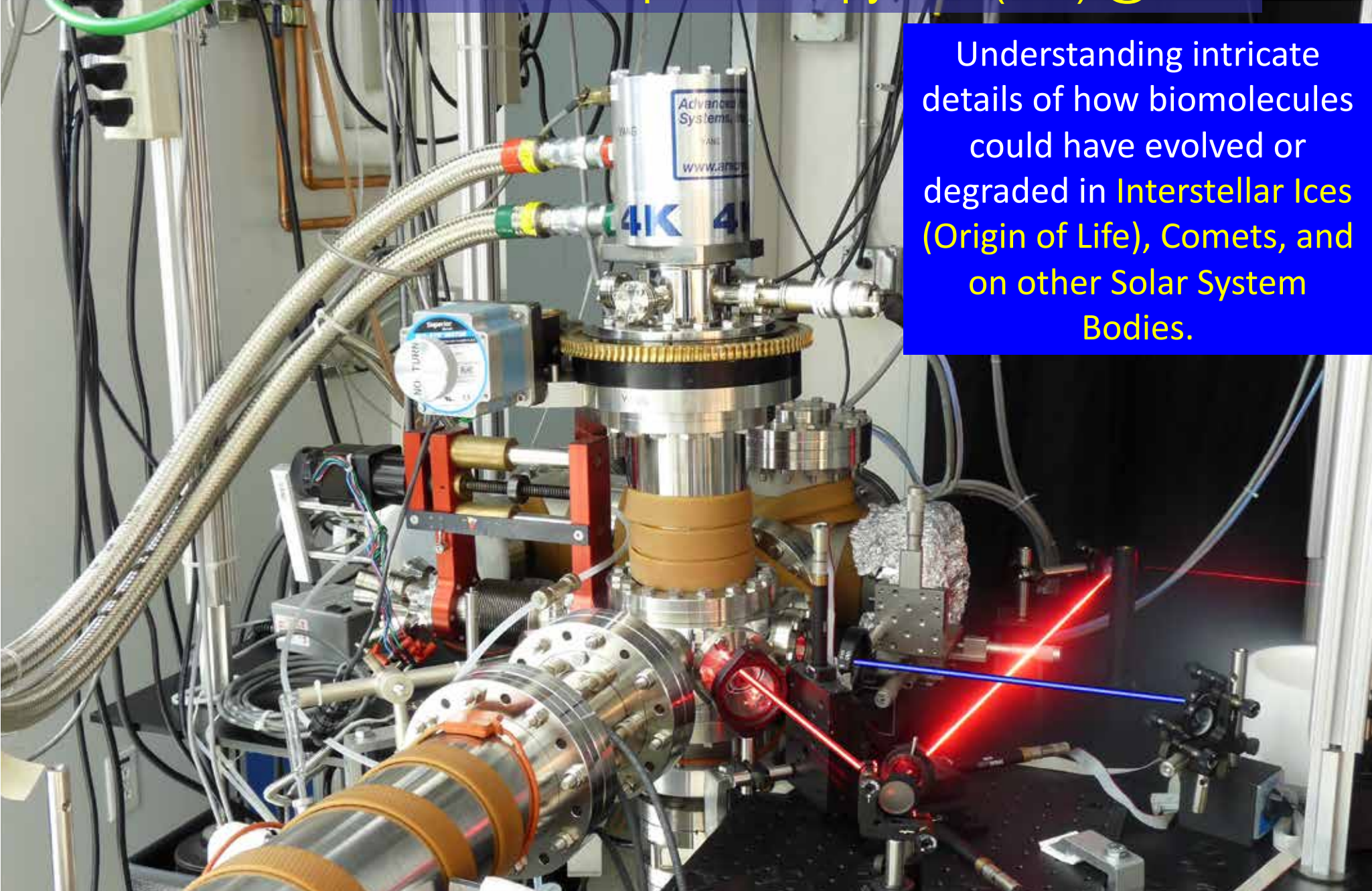


Dworkin et al. *Proc. Nat. Acad. Sci.* **98**, 815 (2001); Bernstein et al. *Nature* **416**, 401 (2002); Muñoz-Caro et al. *Nature* **416**, 403 (2002)

Understanding Prebiotic Chemistry in Comets

At the Ice Spectroscopy Lab (ISL) @ JPL

Understanding intricate details of how biomolecules could have evolved or degraded in **Interstellar Ices** (Origin of Life), Comets, and on other Solar System Bodies.

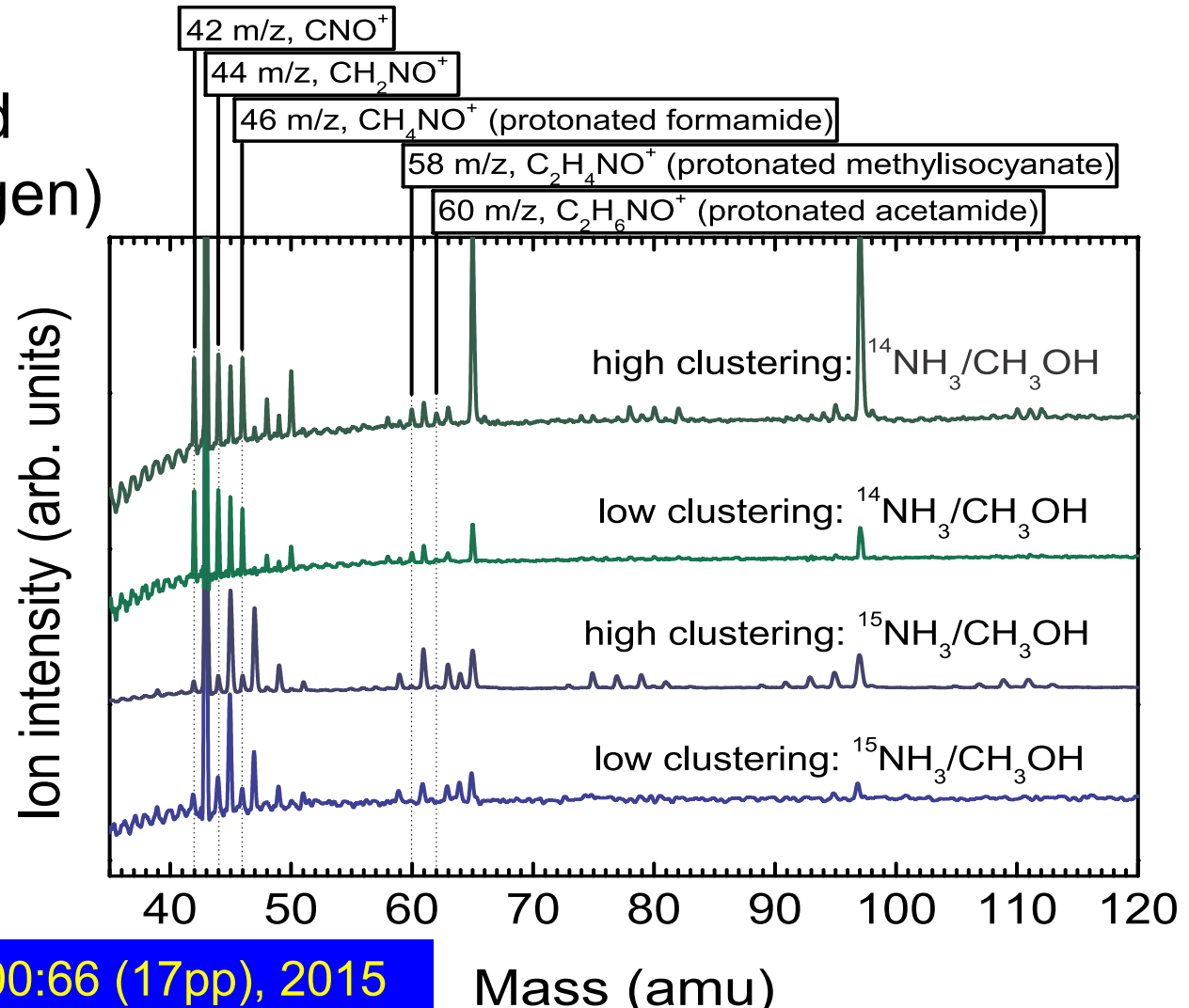


Prebiotic Molecules in Primordial Ice Analogs

Snapshots/Scooping the Evolution of Primordial Ice Analogs

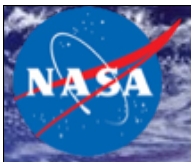
Methanol (Carbon),
Ammonia (Nitrogen), and
Water (Oxygen & Hydrogen)

Interstellar /
Cometary Ice
Analog
Produce Key
Building Blocks
Of Life upon
Radiation
Processing



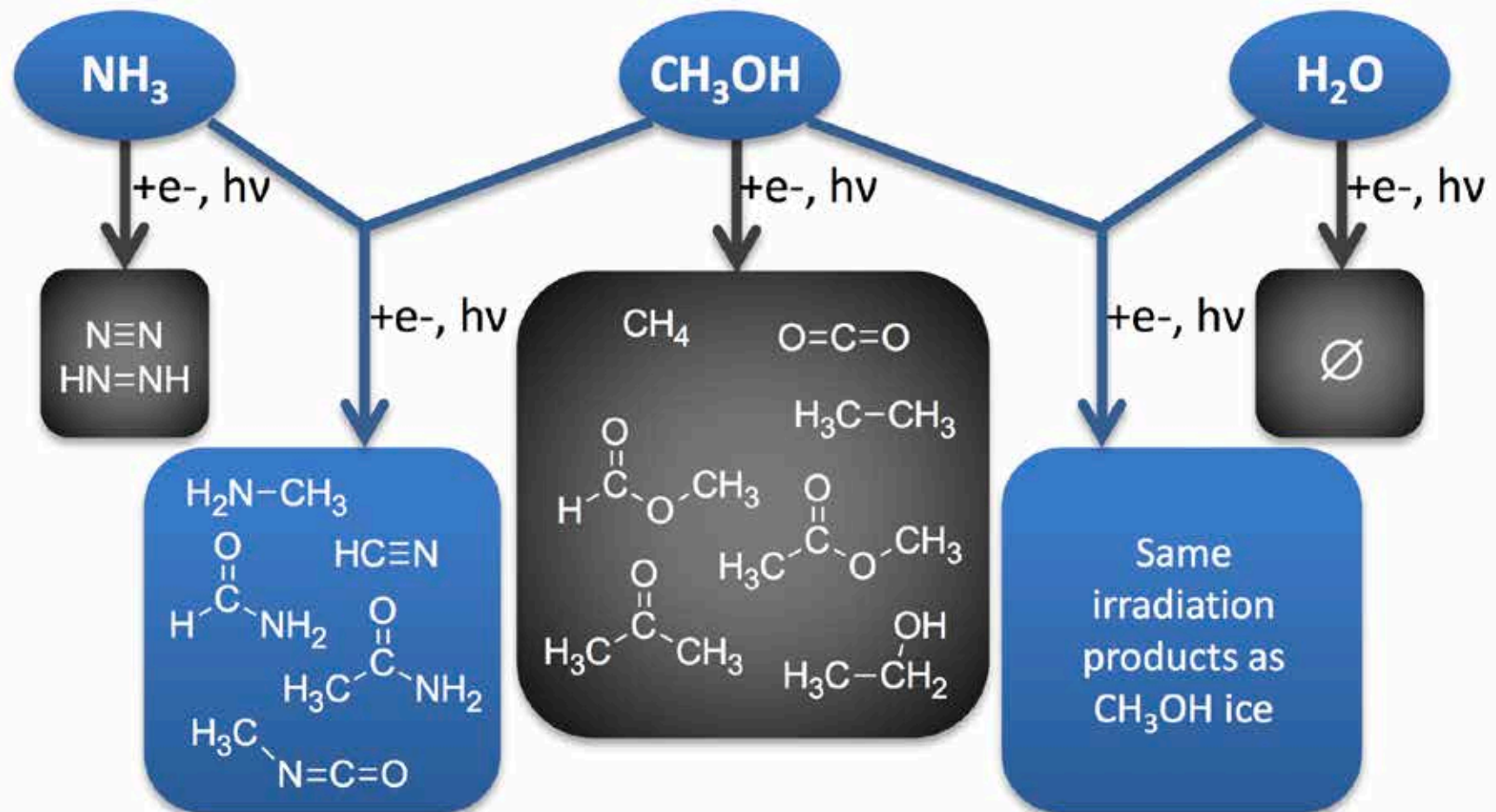
Henderson and Gudipati ApJ - 800:66 (17pp), 2015

Mass (amu)



Molecules found in interstellar ice analogs

Irradiation Products of Single and Dual-Component Ices, 5 K



Many of these molecules are detected later by Rosetta-ROSINA

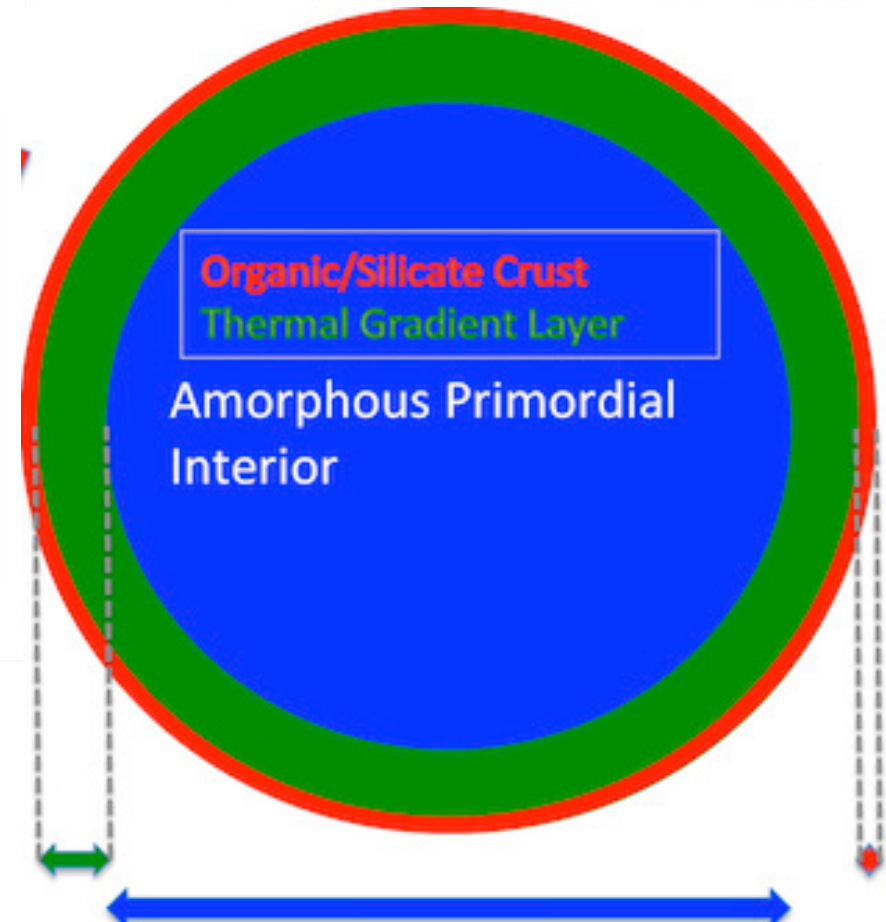
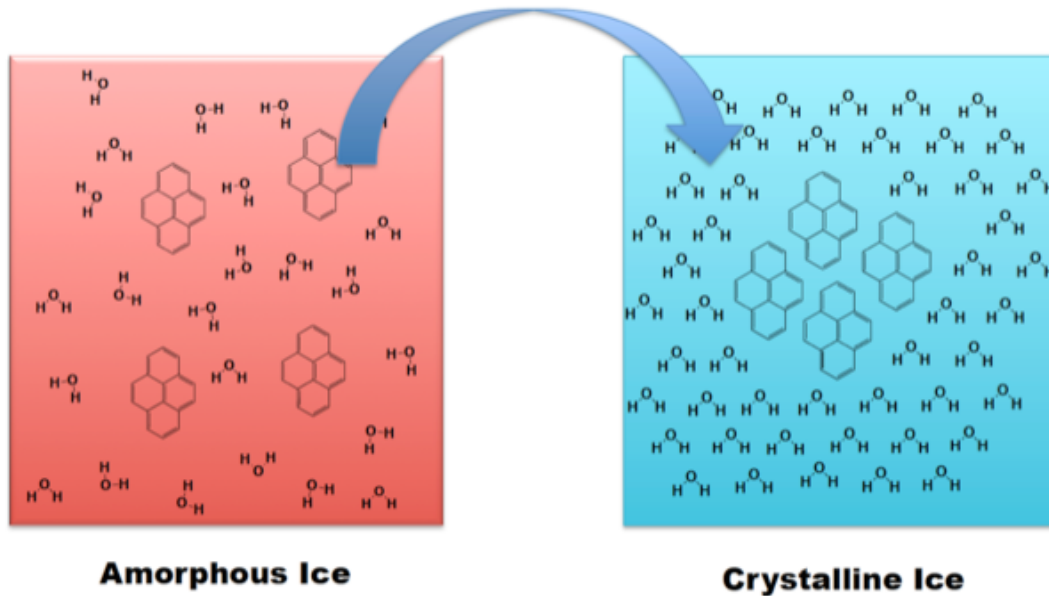
NH₃ less reactive than CH₃OH under radiation



Are Comets Like Deep Fried Ice Cream?

Rosetta (ESA/NASA) found ~10 cm Crust

Phase Transition



1-10 m

1-10 km

~0.1m

Lignell & Gudipati J. Phys. Chem A. 119 (2015) 2607



What are Comets and Why are they Important?



Comets are made of most primitive matter in our Solar System!

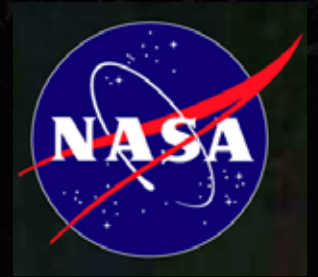
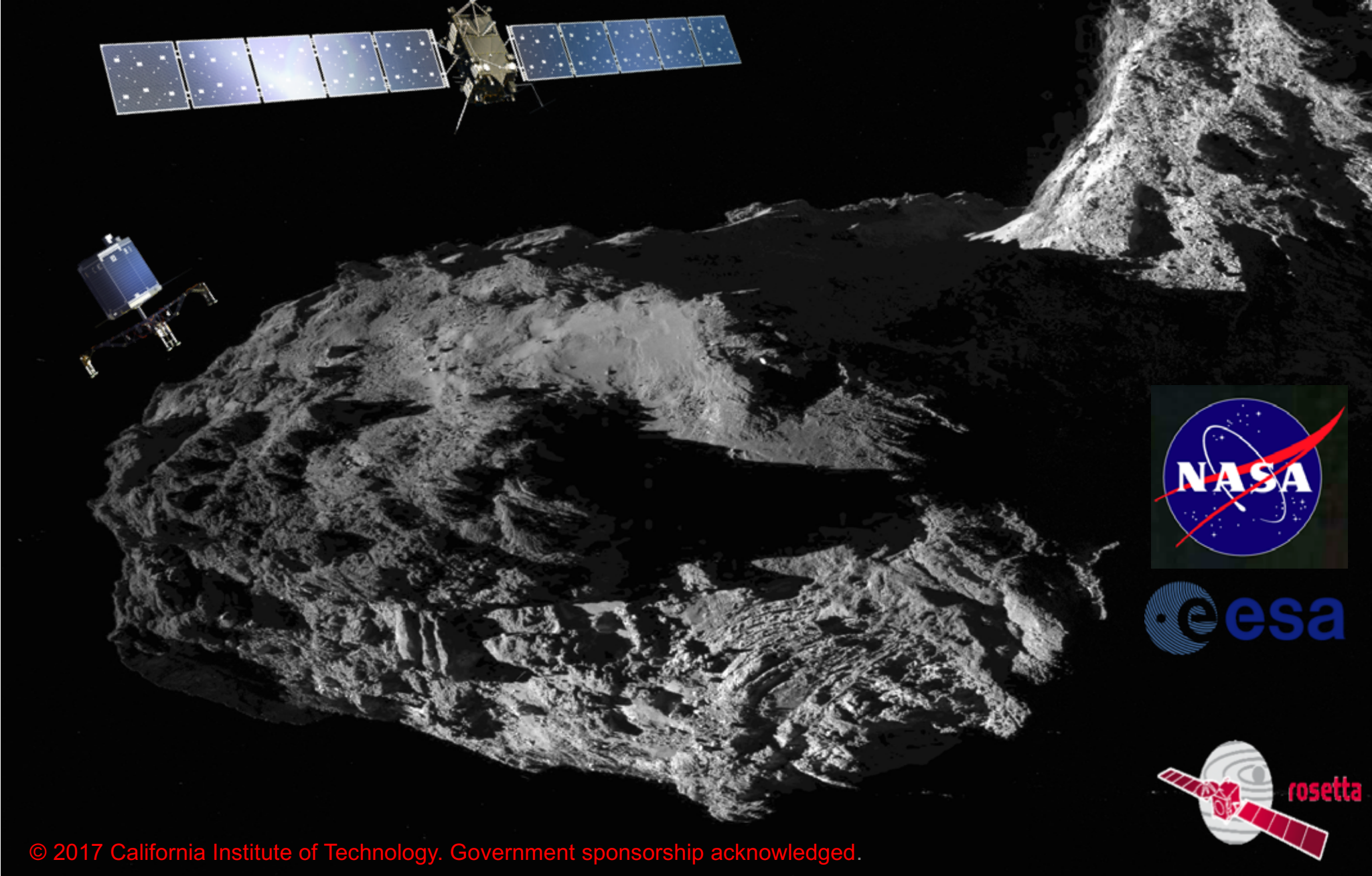
Comets are from Kuiper Belt and Oort Cloud.

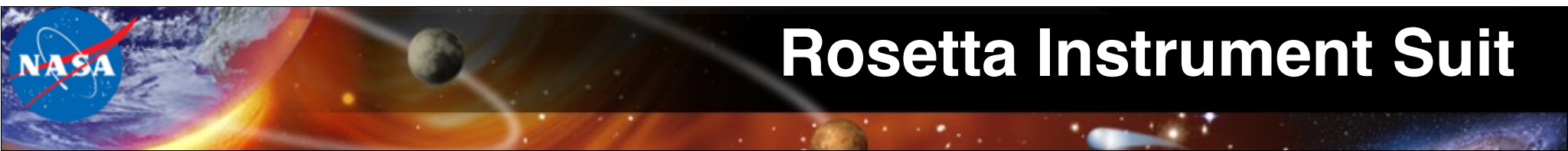
Comets are porous kilometer-sized & odd-shaped icy bodies.

Did Comets and Asteroids bring primordial matter to Earth
~4 Billion Years ago & kick starting the Origin of Life on Earth?

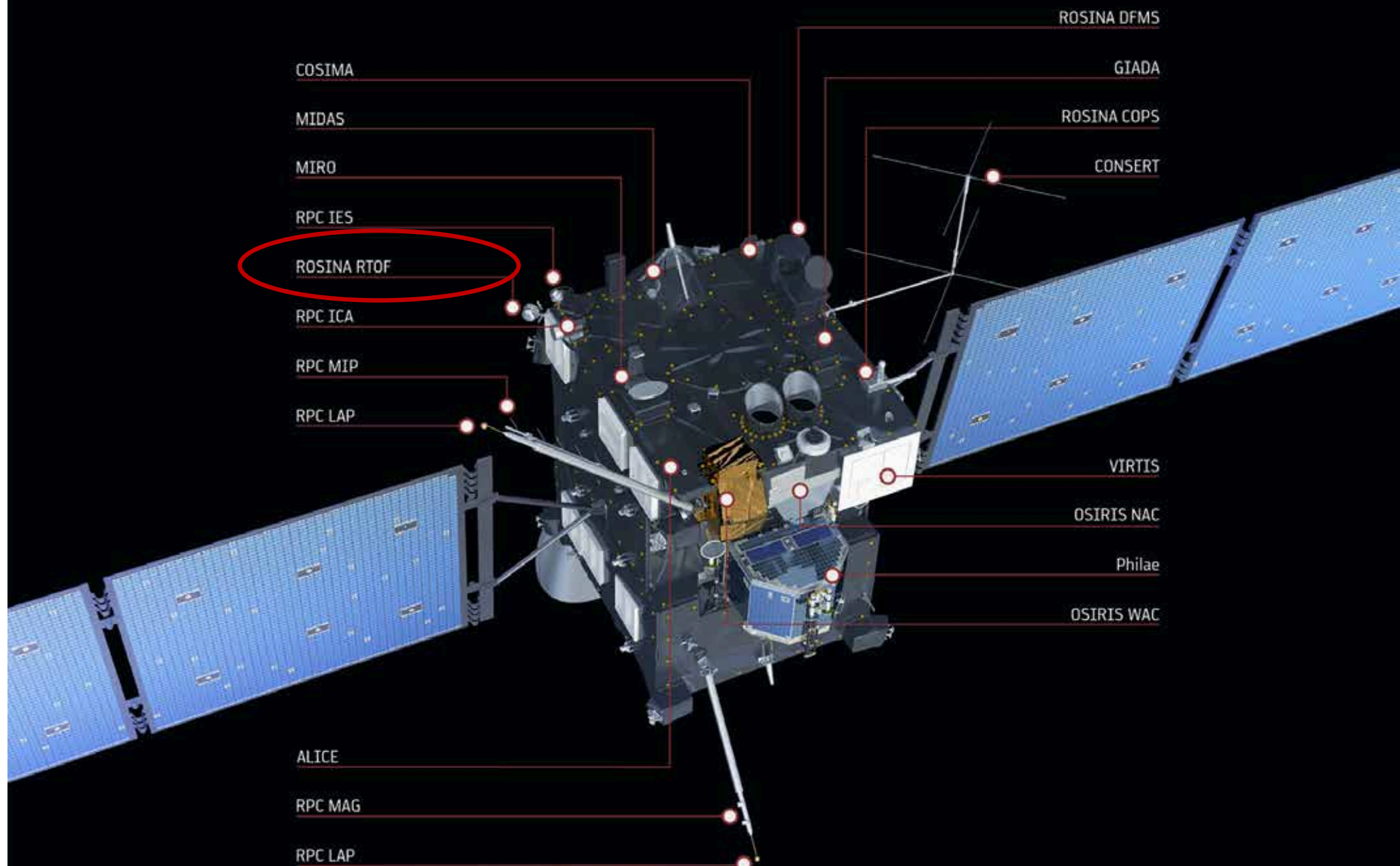


Rosetta Mission to the Comet 67P/Churyumov-Gerasimenko



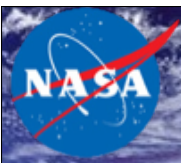


Rosetta Instrument Suit



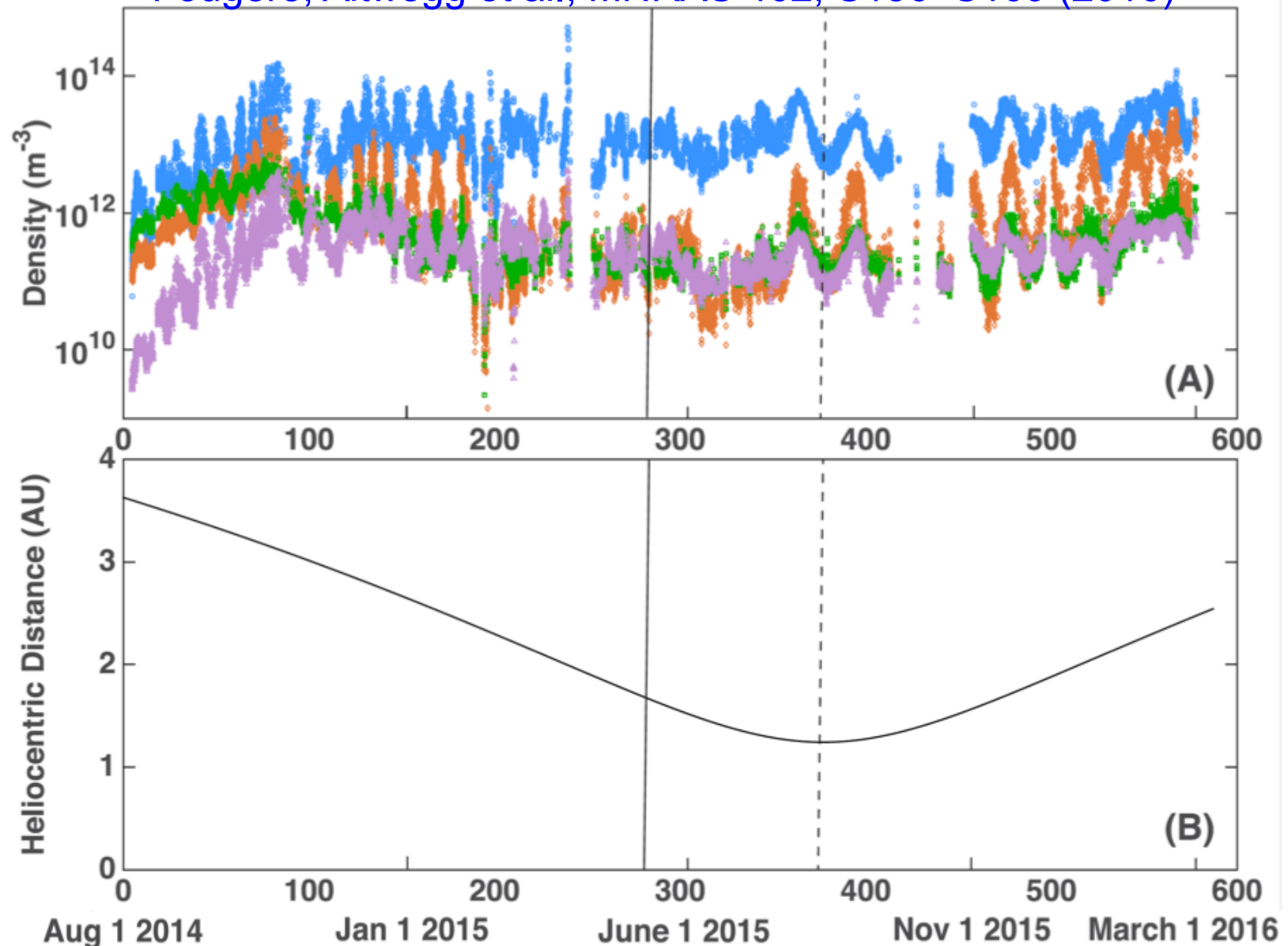


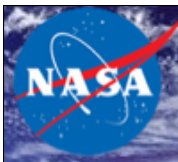
The ROSINA Double Focusing Mass Spectrometer (DFMS) on Board Rosetta Spacecraft (Lead by Prof. Kathrin Altwegg) made Outstanding Observations on the Comet 67P/CG



Oxygen Molecules from Comet 67P/C

Fougere, Altwegg et al., MNRAS 462, S156–S169 (2016)

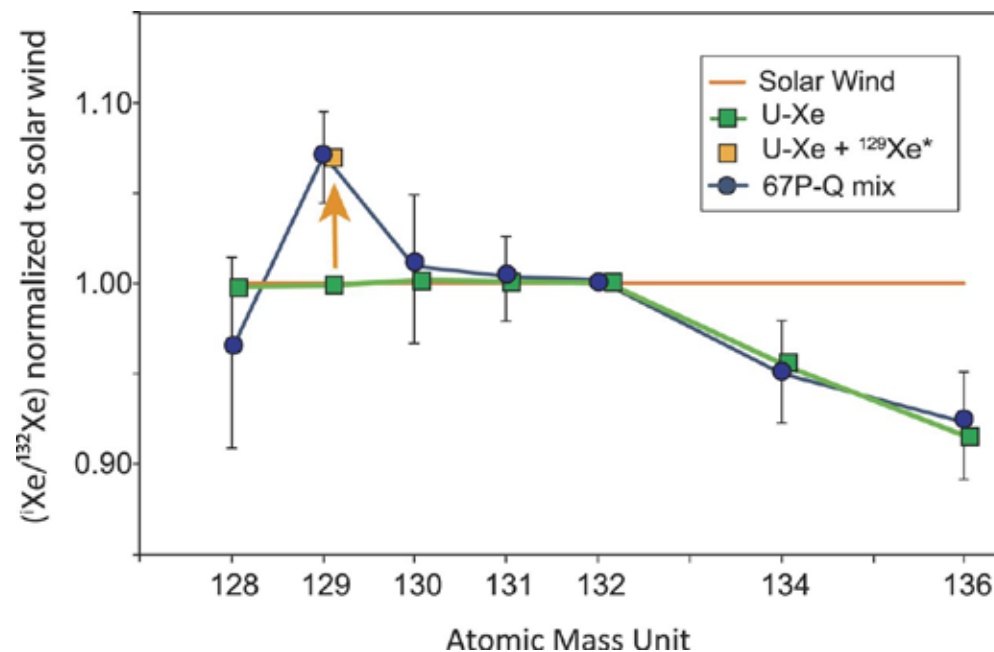




Indication that Comets brought Xe to Earth

Xenon isotopes in 67P/Churyumov-Gerasimenko show that comets contributed to Earth's atmosphere

by B. Marty, K. Altwegg, H. Balsiger, A. Bar-Nun, D. V. Bekaert, J.-J. Berthelier, A. Bieler, C. Briois, U. Calmonte, M. Combi, J. De Keyser, B. Fiethe, S. A. Fuselier, S. Gasc, T. I. Gombosi, K. C. Hansen, M. Hässig, A. Jäckel, E. Kopp, A. Korth, L. Le Roy, U. Mall, O. Mousis, T. Owen, H. Rème, M. Rubin, T. Sémon, C.-Y. Tzou, J. H. Waite, and P. Wurz



Science
Volume 356(6342):1069-1072
June 9, 2017



NASA Chemical Zoo of a Comet Detected by ROSINA

ROSETTA Zoo

Macromolecules

Methane
Ethane
Propane
Butane
Pentane
Hexane
Heptane



S₂
S₃
S₄
Methanethiole (CH₃SH)
Ethanethiol (C₂H₅SH)
Thioformaldehyde (CH₂S)

C_nH_m
C_nH_mO
C_nH_mS
C_nH_mN
C_nH_mON
C_nH_mOS
n=1...8

Unsaturated
carbon chains and rings

Ammonia
Methylamine
Ethylamine

Cyanogen
(C₂N₂)

Formic acid
Acetic acid
Acetaldehyde
Ethylenglycol
Propylenglycol
Butanamide

Argon
Krypton
Xenon

HF
HCl
CH₃Cl
HBr
P

Acetylene
HCN
Acetonitril
Formaldehyde

Benzene
Toluene
Xylene
Benzoic acid
Naphthalene

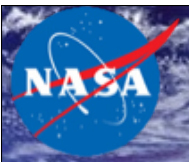
Methanol
Ethanol
Propanol
Butanol
Pentanol

Nitrogen
Oxygen
Hydrogenperoxide
Carbon monoxide
Carbon dioxide

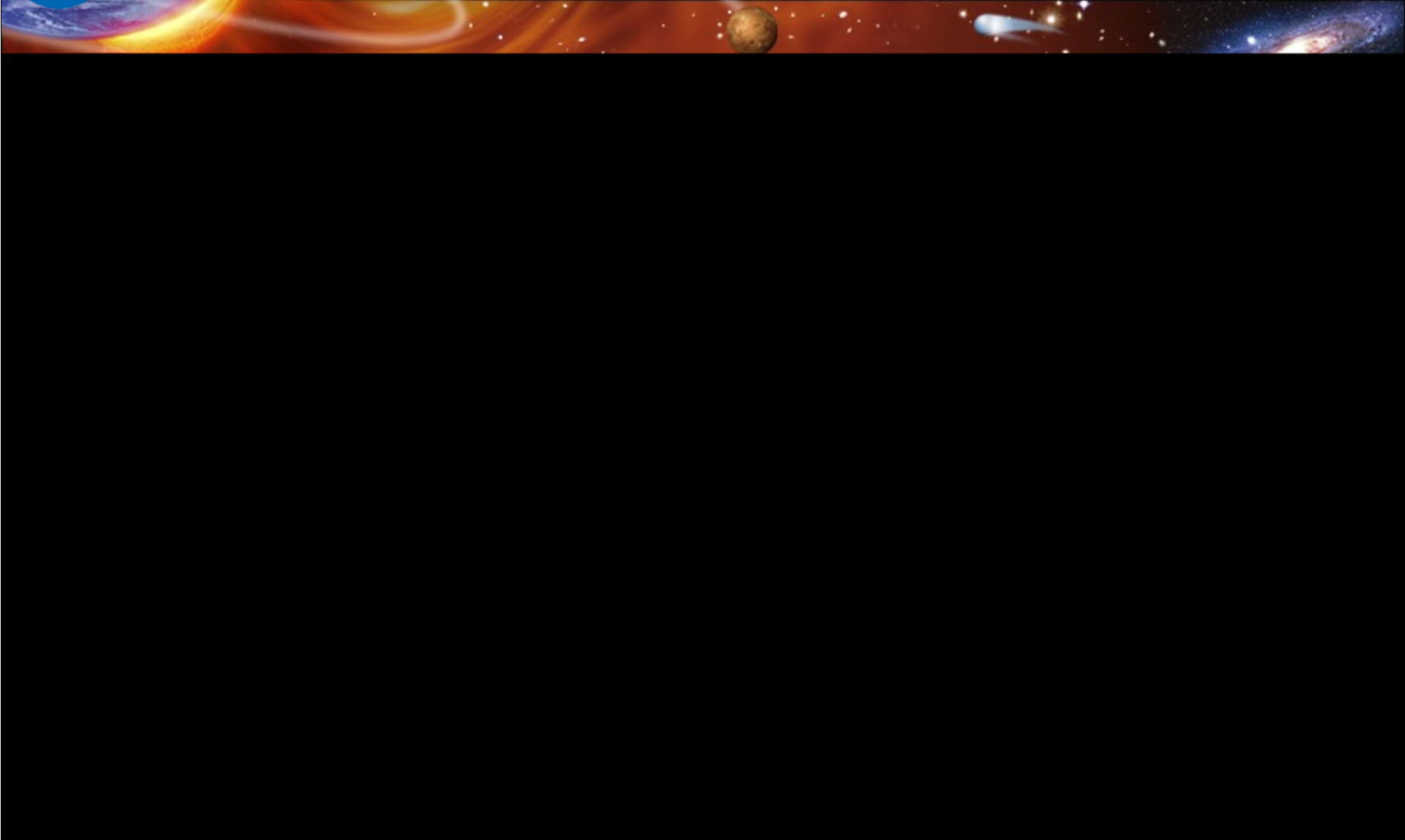
Hydrogensulfide
Carbonylsulfide
Sulfur monoxide
Sulfur dioxide
Carbon disulfide

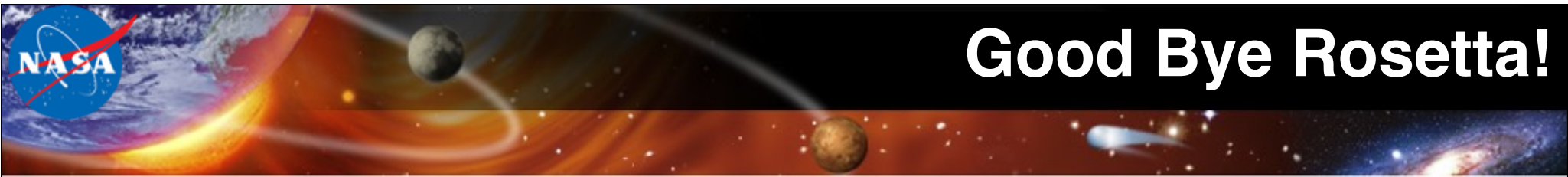
Na, Si, K

O₂
N₂
S₂
HCN
Ar
Kr
Xe
HCOOH
Na
K
P
Glycine
(Amino Acid)

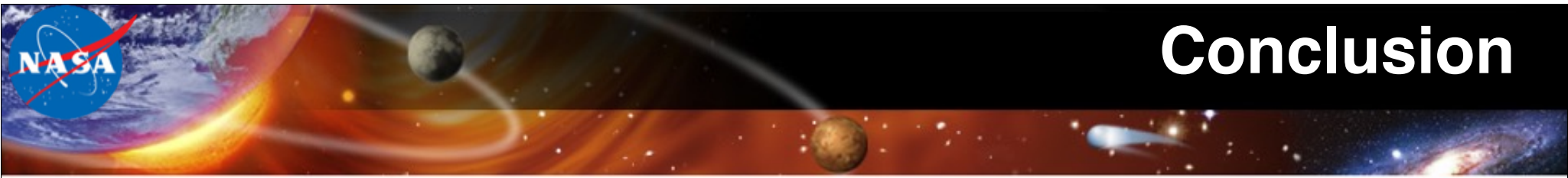


The Rosetta Mission to Comet 67P-CG





Good Bye Rosetta!



Conclusion

Comets Preserve the most Primitive Matter
In Our Solar System!

Comets and Asteroids could have Triggered
The Origin of Life on Earth 4 Billion Years Ago

Comet/Asteroid Impact ~70 Million Years Ago
Lead to the Extinction of Dinosaurs

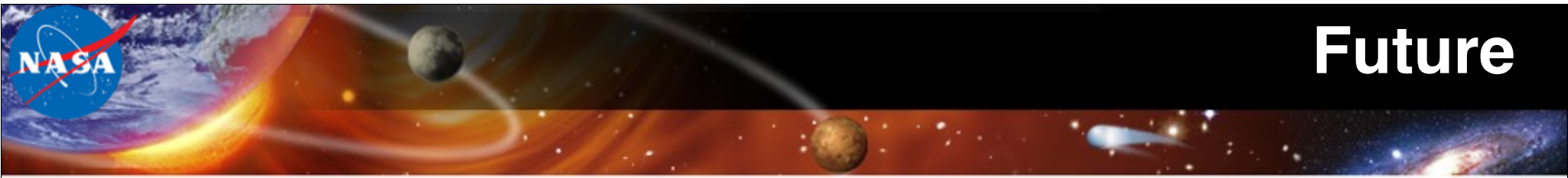
And Perhaps Triggered the Evolution towards
HUMANS!

Scientists are Searching for Extraterrestrial Life & Intelligence

No Signs or Signals **YET**

Life in its Beauty and Diversity is **ONLY** on Earth

Let us Protect and Preserve Our Living Ecosystem



We still do not understand
How a comet's nucleus is structured
How cold its interior is
Whether amorphous ice is present
Whether primordial molecules are present
When and where comets are made

You – the Younger Generation in the Audience
Will Address Some of These Questions

Thank You

